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U.S. Army Aircrew Helmets: Head Injury Mitigation Technology (Reprint)

By

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Aircrew Protection Division

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Head injury remains the predominant cause of severe and fatal injuries to Army aircrew involved in helicopter mishaps. As a means to prevent injuries or reduce their severity, the U.S. Army has continuously sought improvements to aviator helmets. Numerous improvements have resulted from analysis of helmets involved in aviation accidents and the wearer's injuries. It is believed that the newest Army aviator helmet, the HGU-56/P, offers significant improvements over earlier designs. This paper presents a chronology of Army aviator helmets with descriptions defining their differences and improvements.

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U.S. Army Aircrew Helmets: Head Injury Mitigation Technology

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1. SUMMARY

Head injury remains the predominant cause of severe and fatal injuries to Army aircrew involved in helicopter mishaps. As a means to prevent injuries or reduce their severity, the U.S. Army has continuously sought improvements to aviator helmets. Numerous improvements have resulted from analysis of helmets involved in aviation accidents and the wearer's injuries. It is believed that the newest Army aviator helmet, the HGU-56/P, offers significant improvements over earlier designs. This paper presents a chronology of Army aviator helmets with descriptions defining their differences and improvements.

2. LIST OF SYMBOLS

cm	Centimeter
dB	Decibel
G	Acceleration, gravity constant (32.17 ft/sec^2 or 9.81 m/sec^2)
gm	Gram
hz	Hertz
m	Mass
ml	Milliliter
N	Newtons

3. SUBJECT MATTER KEYWORDS

Helmets
Protective headgear
Impact protection
SPH-4
SPH-4B
IHADDS
HGU-56/P
Head injury

4. INTRODUCTION

The high frequency of head injury in U.S. Army helicopter mishaps is well documented by Bezreh [1], Berner [2], Shanahan [3], and Shannon [4]. Aircrew helmets have played an important role in mitigating injury in survivable mishaps. The Army has strived to improve the crashworthiness of helicopters by requiring energy-absorbing seats and landing gear, and crashworthy fuel systems in modern aircraft [5]. Aircrew helmets have received several improvements to increase impact protection. Yet, head injury remains the leading cause of contact related fatal and severe injury in Army helicopter mishaps [3].

Several helmet types have been used by Army aircrew in the rotary wing environment. A brief chronology is presented in Table 1. The Army aircrew protective helmet #5 (APH-5), shown in Figure 1, was widely fielded in 1960 with significant reductions in head injury within 4 years [1]. Yet, the APH-5 provided minimal hearing protection from ambient cockpit noise.

To increase sound attenuation, the Army accepted the sound protective helmet #4 (SPH-4), shown in Figure 2, as a new standard helmet in 1969. This design was a derivative of the U.S. Navy SPH-3 helmet which offered increased noise attenuation for the helicopter sonar operators. The SPH-4 was based on a new shell design which accommodated large volume rigid earcups with state-of-the-art noise attenuation.

Table 1. Army aviation helmet chronology.

Year	Helmet	Characteristic
1960	APH-5	Navy design, general purpose
1969	SPH-4	New shell contour, improved sound attenuation, general purpose
1974	SPH-4	35% thicker foam liner
1982	SPH-4	Thinner shell
1984	IHADSS	Equivalent to SPH-4, specific to AH-64 aircraft
1989	SPH-4B	New shell material, liner, fitting, retention, earcup, and visor systems (Lower weight)
1995	HGU-56/P	All new, general purpose and aircraft unique design (Improved impact protection)

Several improvements were made to the basic SPH-4 helmet. In 1974, the foam liner was changed from 0.375 inches to 0.5 inches in thickness. In 1982, the helmet shell was reduced in thickness to reduce helmet weight. This helmet was a general purpose helmet and variants are still in use by some active and reserve Army aircrew.

The introduction of the AH-64 Apache helicopter to the Army helicopter fleet in 1984 resulted in an aircraft specific helmet. This helmet is the integrated helmet and display sighting system (IHADSS), shown in Figure 3. The IHADSS utilizes a unique shell design which houses infra-red sensors for slewing pilotage and weaponry systems. It is also designed to receive a helmet display unit (HDU) which can deliver weapon targeting, forward looking infra-red (FLIR), and flight instrumentation symbology to each crewmember.

Paper presented at an AGARD AMP Specialists' Meeting on "Impact Head Injury: Responses, Mechanisms, Tolerance, Treatment and Countermeasures", held in Mescalero, New Mexico, USA, 7-9 November 1996, and published in CP-597.

Figure 1. APH-5 aircrew helmet.

Figure 2. SPH-4 aircrew helmet.

At the U.S. Army Aeromedical Research Laboratory (USAARL), personal protective equipment involved in Army aviation mishaps are evaluated to determine its effectiveness at reducing and preventing injuries. This program is formally recognized as ALSERP, the Aviation Life Support Equipment Retrieval Program. As a result of the findings of this program and through collaboration with the SPH-4 helmet program manager and the Gentex Corporation, design improvements were made to the SPH-4, and the SPH-4B was introduced in 1989. The SPH-4B, shown in Figure 4, utilizes the same shell contour, but is constructed of different shell material, energy liners, retention system, earcups, and visor system.

Figure 3. IHADSS aircrew helmet.

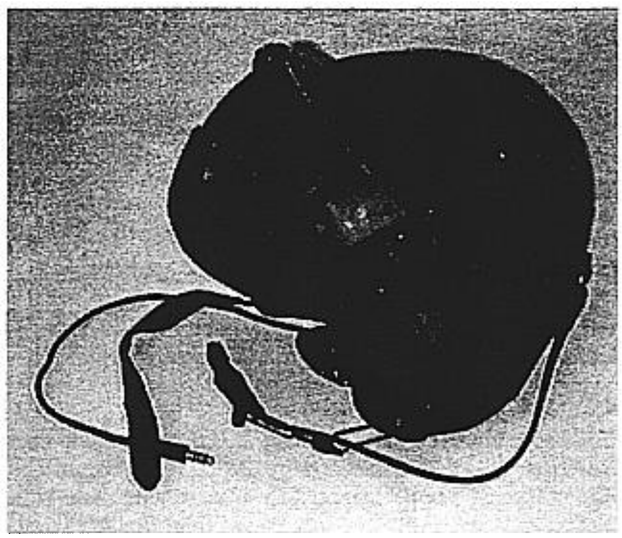

Figure 4. SPH-4B aircrew helmet.

In 1983, the Army initiated a development program to develop a completely new Army aircrew helmet, the head gear unit #56, personal (HGU-56/P). The original HGU-56/P configuration was evaluated by the Army in 1985, but did not receive favorable reviews. The program was resurrected in 1988 with revised requirements. The revised HGU-56/P, shown in Figure 5, was finally introduced in 1995 and is currently in full production. This helmet possesses greater impact protection than previously available in aviation helmets and is intended to become a standard helmet platform for all Army helicopters.

Another helmet currently being developed is aircraft specific. This is the RAH-66 Comanche helicopter helmet, shown in Figure 6. The RAH-66 helicopter is unique from other helicopters in that it demands high man-machine integration for transfer of flight, mission, and targeting data to be highly effective. The original intent of the prime contractor for the RAH-66 was to develop a specific helmet unique to the Comanche to achieve the desired man-machine interaction. An effort is currently funded to determine the feasibility of adopting the HGU-56/P helmet as a mounting platform for the RAH-66 unique avionics, thereby keeping the HGU-56/P as a common helmet across the Army helicopter community.

Figure 5. HGU-56/P aircrew helmet.

5. HELMET COMPONENTS

The helicopter aircrew helmet is best described as an assembly of subcomponents. Seven major subcomponents, shell, energy liner, fitting, retention, communication, visor, and mission or aircraft specific systems configure the HGU-56/P helmet assembly.

5.1 Shell

Brief descriptions of aircrew helmet shells are provided in Table 2. The HGU-56/P utilizes a hybrid construction of graphite and SPECTRA® 1000, embedded in an epoxy resin in its shell construction.

The graphite provides stiffness and rigidity to the shell for a stable platform of optical systems. The SPECTRA® is used to defeat a tear penetration requirement. This requirement was intended to ensure the final product was structurally tough and would withstand multiple impacts. This test is essentially a shear test of the composite laminate. Kevlar®, a very high tensile strength material, performs poorly in this test.

The helmet shell provides three primary purposes. First it is the structural member, or foundation, of the helmet used for mounting other systems. Second, it distributes impact loads over greater surface areas. This reduces the likelihood of receiving point contact loads. Third, it resists penetration from rigid contact surfaces.

Figure 6. Comanche aircrew helmet.

Table 2. Helmet shell materials.

Shell	Material
APH-5	Fiberglass
SPH-4	Fiberglass
SPH-4 (1982)	Fiberglass
IHADSS	Kevlar® & graphite
SPH-4B	Kevlar®
HGU-56/P	SPECTRA® & graphite

It is important that the shell not be so stiff as to prevent flexure during impact. Shell deformation into the energy liner is an effective means of reducing the energy transmitted to the wearer as long as the shell does not permit a concentrated force or "bottoming."

5.2 Energy absorbing liner

From an impact protection perspective, the energy liner is the most critical component in the protective helmet. All of the Army aviator helmets utilize energy liners manufactured from expanded bead polystyrene. Differences between helmets are based on the energy liner thickness and its density. These differences are defined in Table 3.

Table 3. Helmet energy liner differences.

Helmet	Thickness (cm)	Density (gm/ml)
APH-5	1.27	0.08
SPH-4	0.96	0.08
SPH-4 (1974)	1.27	0.07
IHADSS	~1.4	0.07
SPH-4B	1.6	0.04
HGU-56/P	1.78	0.035

The noticeable trend in Table 3 is the increase in liner thickness and decreases in liner density. This follows USAARL's belief that head tolerance to blunt impacts is increased if the transmitted head acceleration is reduced. The increase in energy liner thickness provides an increased stopping distance, while the reduced density results in a lower force transmitted to the head.

5.3 Fitting systems

Significant advances in fitting system technology have been realized over the last 30 years. A brief description of the different technologies is provided in Table 4.

Table 4. Helmet fitting systems

Helmet	Fitting system discription
APH-5	Foam pads
SPH-4	Sling suspension
IHADSS	Basket & spacers
SPH-4B	Thermoplastic liner (TPL®)
HGU-56/P	Thermoplastic liner (TPL®)

The APH-5 utilized leather covered foam pads of various thicknesses to provide individual helmet fitting. These pads were provided with either self adhesive or hook and pile (Velcro®) backing. The SPH-4s were configured with a sling suspension, shown in Figure 7 with a cutaway helmet. Individual adjustments were accomplished by varying the lengths of the three cross straps and the headband. The IHADSS helmet is configured with an inner basket. This basket is shown in Figure 8. Individual fittings are made by adjusting the crown drawstring and placing Velcro® fitting pads in the brow and nape area. The SPH-4B and HGU-56/P both utilize the thermoplastic liner (TPL®). This is a multiple layer of thin thermoplastic sheets, each formed with egg carton type dimples covered with a washable cloth fabric. The pre-formed TPL® sheets are assembled by the manufacturer. Approximately 60 to 80 percent of individuals are fitted adequately with the preformed TPL®. Individual fitting is accomplished by heating the TPL® until the thermoplastic layers become pliable, then having the individual don the TPL® and helmet until the TPL® has cooled and formed to the shape of the wearer's head.

Figure 7. SPH-4 sling suspension system.

Figure 8. IHADSS inner basket.

While helmet fitting systems are not intended as an energy absorbing material for impact protection, it does influence helmet performance in a laboratory setting. The SPH-4 sling suspension provided energy attenuation by plastic bending of the six metal attachment clips. The TPL® provides assistance by maintaining offset distances prior to impact except in those cases of custom fitting where the TPL® layers were compressed entirely. It also provides load distribution between the skull and energy liner.

5.4 Retention systems

The helmet retention system is critical for head impact safety by securing the helmet snugly to the wearer's head. Several improvements have been made in the helmet retention systems. Table 5 provides a brief discription of the different systems utilized in the Army aviation helmets.

Table 5. Helmet retention systems.

Helmet	Type system
APH-5	separate
SPH-4	harness
IHADSS	integral
SPH-4B	harness
HGU-56/P	integral

The APH-5 utilized separate straps for the chin and nape straps. Each of these attached separately to the helmet shell. This configuration is considered inadequate because retention system effectiveness is dependent on the helmet shell stiffness and the mounting locations of the strap to the shell.

The SPH-4 and SPH-4B helmets utilize a harness configuration which contain the earcups. These two harnesses are shown in Figures 9 and 10. The original SPH-4 design was poor because the chinstrap load was carried through four attachment tabs, the webbing containing the earcups, and finally to the chinstrap itself. Failures occurred at the tab and webbing or the chinstrap and webbing attachment points. The pull-the-dot chin-strap fasteners also caused helmet loss. The SPH-4B utilized an improved design by routing the chinstrap webbing directly to the helmet shell. Thus, chinstrap loading was through a continuous piece of material instead of multiple links. The harness material containing the earcups could also be adjusted in length to pull against the wearer's nape. When properly adjusted, the nape increased the helmet's stability and retention characteristics.

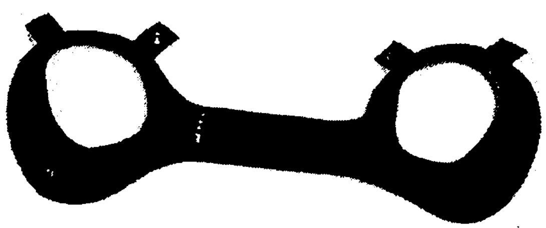

Figure 9. SPH-4 retention harness.

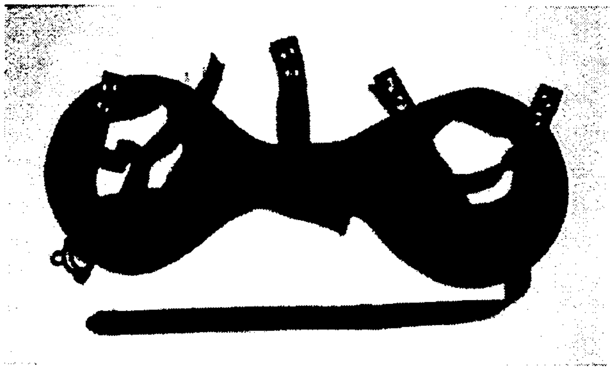

Figure 10. SPH-4B retention harness.

The IHADSS helmet retention system is similar to the SPH-4B system. Its chinstrap connects to the lower portion of a "V" strap. The upper legs of the "V" strap attach directly to the helmet shell and provide stability. The rearward strap weaves through the harness material which contains the earcups. This material wraps around the wearer's nape and can be adjusted snugly to improve helmet stability.

The HGU-56/P also utilizes a chinstrap which attaches to a "V" strap similar to the IHADSS and SPH-4B. The difference is that no harness is used to contain the eacups. The earcups are attached to the "V" straps with Velcro®. The "V" straps are also integrated with the nape strap pad with adjustable webbing. This configuration yields a low elongation chinstrap assembly and a stable helmet when properly adjusted.

The method used to attach the chinstrap is critical. Single snap fasteners, as used on the APH-5 and original SPH-4s, allowed frequent helmet loss in survivable mishaps [6,7]. Double snaps improved retention performance, but did not eliminate helmet loss. The SPH-4B and HGU-56/P both utilize only double D-rings for the attachment and adjustment of the chinstrap.

5.5 Earcups

The APH-5 helmet utilized foam earcups and provided little ambient noise attenuation. The SPH-4 provided much improved sound attenuation by utilizing thick and rigid earcups. A cross section view of a standard SPH-4 earcup is shown in Figure 11.

Through the USAARL ALSERP, it was recognized that aircrew basilar skull fractures were often accompanied with fractured earcups [8]. Static testing of the standard SPH-4 earcup revealed fracture occurred at over 22,000 Newtons. Yet, the temporoparietal region of the human skull can fracture under loads half as great [9].

The IHADSS helmet contains earcups that are rigid, but fracture at loads below the standard SPH-4 earcups. The SPH-4B and HGU-56/P helmets both contain crushable earcups which yield at loads below human threshold. Crosssectional views of these earcups are shown in Figures 12 and 13.

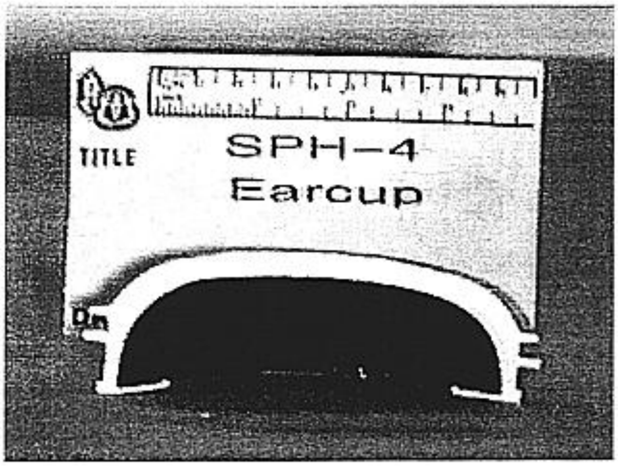

Figure 11. SPH-4 earcup, cross section.

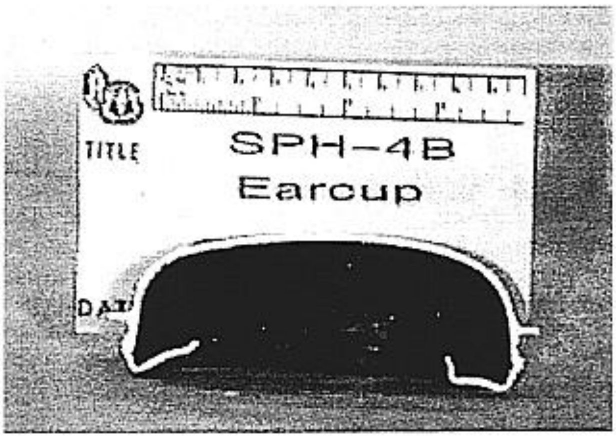

Figure 12. SPH-4B earcup, cross section.

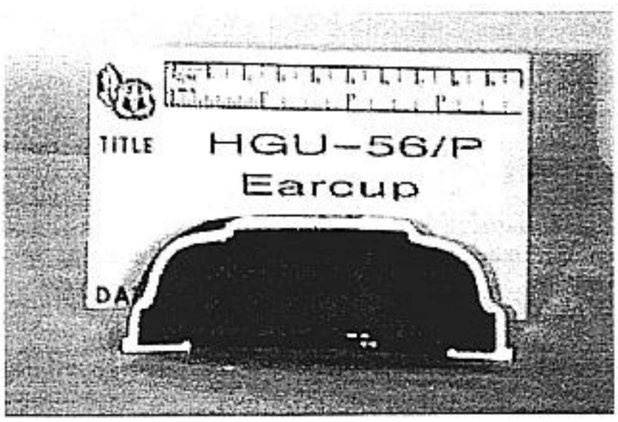

Figure 13. HGU-56/P earcup, cross section.

5.6 Visor systems

Visor systems have experienced little change except for graduating from a single visor design in the SPH-4 and IHADSS to a dual visor design in the SPH-4B and HGU-56/P. The dual visors are preferred by aircrew since it provides an option of a clear visor during low daylight situations and a smoke visor during daylight operations. Single visor design forced the aircrew to select a visor prior to flight or risk eye injury if they decide not to deploy the visor. Both the clear and the smoke visors filter at least 98 percent of ultraviolet rays [10]. Visor use is important as it protects the eyes from flash fires, flying debris, and impact during crashes. Early visors were made from acrylic and frequently fractured when impacted. Current visors are made from polycarbonate and rarely fracture.

5.7 Ancillary equipment

Depending on the mission and the aircraft being flown, various ancillary equipment can be used with aircrew helmets. Listed in Table 6 are the helmets and various compatible pieces of equipment.

The oxygen mask requirement is necessary because of high altitude missions (greater than 10,000 feet) in mountainous regions. Usually these missions are associated with the special operation forces and emergency rescues.

The PNVS-5 is an early generation night vision goggle which has been replaced with the ANVIS-6 goggle. These devices are necessary to reduce risk when missions are required to be conducted at night.

The threat of chemical and biological warfare necessitate the requirement for chemical and biological protective respirators (CBR mask).

Table 6. Helmet ancillary equipment.

Helmet	Compatible equipment
APH-5	Oxygen mask
SPH-4	AN/PVS-5, ANVIS-6, oxygen mask, CBR mask, AH-1 mechanical tracking& targeting system
IHADSS	AH-64 Infra-red head tracker & HDU, CBR mask, ANVIS-6
SPH-4B	PNVS-5, ANVIS-6, oxygen mask, CBR mask, AH-1 mechanical tracking& targeting system
HGU-56/P	ANVIS-6, oxygen mask, CBR mask, AH-1 mechanical tracking& targeting system, AH-64 Infra-red head tracker & HDU

The AH-1 and AH-64 helicopters both have weapon systems capable of being aimed by sensing the position of the helmet in the cockpit. The AH-1 Cobra uses a mechanical linkage attached directly to the helmet to measure the helmets position and orientation. The AH-64 Apache uses infra-red sensors mounted on the helmet to sense orientation.

6. PROTECTIVE REQUIREMENTS

The basic protective requirements for the Army helicopter aircrew helmet have become more stringent in an effort to improve aircrew safety. These requirements include impact, retention, tear resistance, and sound attenuation.

6.1 Impact protection

The helicoper aviator helmet protective requirements have received considerable changes over the past 30 years. Table 7 provides some basic details on the requirements for each helmet. The APH-5 is not included in this table since its impact requirements were based on the "swing away" test method and are not comparable to the other helmets.

The HGU-56/P has the most stringent impact requirements. These requirements are also applicable to the RAH-66 Comanche helmet development efforts.

Table 7. Impact performance requirements.

Helmet	Impact site	Impact velocity (m/s)	Peak accel (G)
SPH-4			
flat	all	5.3	400
hemi	all	5.3	400
SPH-4 (1982)			
flat	all	5.3	300
IHADSS			
flat	all	5.3	300
SPH-4B			
flat	earcups	6.0	175
flat	other areas	6.0	250
HGU-56/P			
flat	crown	4.9	150
flat	earcup	6.0	150
flat	headband	6.0	175

The headband region acceleration threshold of 175 G was placed in order to prevent concussion to Army crewmembers in survivable mishaps [11]. Surviving a military mishap with a concussion is unacceptable due to potential hazards associated with military crash environments. Unconciousness could lead to an aviator's drowning or capture, depending on the crash location (water or enemy teritory) or burns in the presence of a postcrash fire. Aircrew must remain concious during survivable mishaps to quickly egress the crashed aircraft, provide assistance to fellow crewmembers, and evade hostile search parties.

The 150 G requirement for the crown and earcup region were established to reduce the potential of basilar skull fractures when impacted at those sites [11]. The impact velocity for the crown impact was reduced because direct blunt crown impact at the greater velocity rarely occurs in survivable mishaps.

Impact tests are required to be conducted on a guided free-fall drop tower assembly configured in accordance with the American National Standards Institute ANSI Z90.1-1971 [12]. The USAARL helmet impact tower is shown in Figure 14.

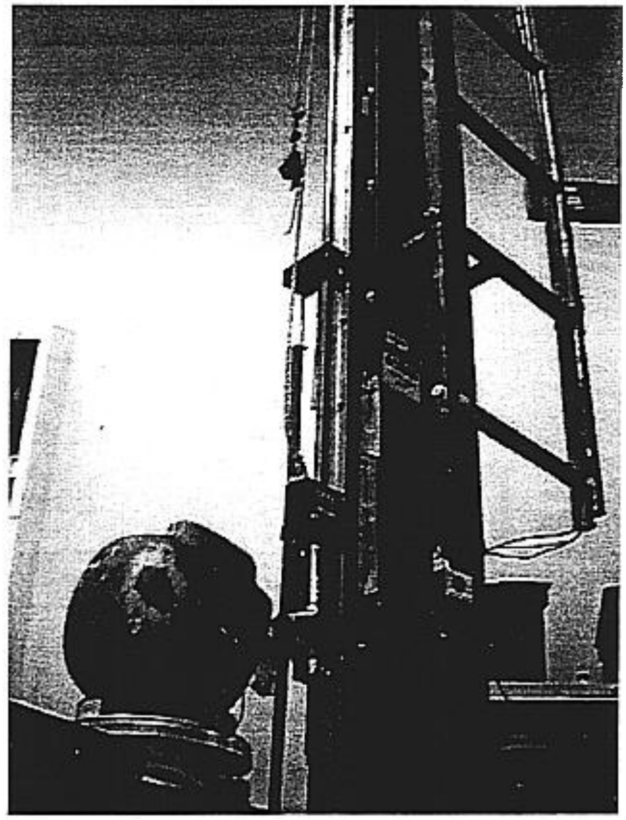

Figure 14. USAARL helmet impact tower.

For the crown and headband impacts, headforms conforming to the Department of Transportation (DOT 218) size B, C, and D are used. Impacts to the earcup region require use of a modified size C headform. This modification includes the downward extension of the headform in the earcup region to increase the contact surface area. Material is removed from the inner surface of the headform to maintain the mass requirement of the size C headform.

All impacts for performance assessments are conducted onto flat impact anvils. The hemispherical anvil was eliminated after ALSERP investigators revealed less than 3 percent of helmet impacts resulted from hemispherically shaped objects, while flat surfaces accounted for over 60 percent [6].

6.2 Helmet retention

Helmet retention assessments are necessary to ensure the basic helmet system, if fitted and worn as designed, will keep the helmet properly positioned on the wearer's head. The Army currently requires only a static strength assessment be performed. In addition to the static test, USAARL routinely conducts dynamic retention tests for comparative purposes.

6.2.1 Static

The static retention test is conducted in accordance with ANSI Z90.1-1979 [13] with one exception, the preweight is 25 pounds instead of 50 pounds. As illustrated in Figure 15, this test requires a static load be applied through a simulated chin onto the chinstrap. The maximum strength and elongation requirements are provided in Table 8. Inspection of Table 8 reveals an increase in static strength requirements. Again, this is a result of ALSERP findings of chinstrap and harness failures in accident helmets [6,7].

Table 8. Static retention requirements.

Helmet	Static strength (pounds)	Maximum elongation (inches)
APH-5	150	no separation
SPH-4	150	no separation
SPH-4 (1982)	300	no separation
IHADSS	300	no separation
SPH-4B	440	1.5
HGU-56/P	440	1.5

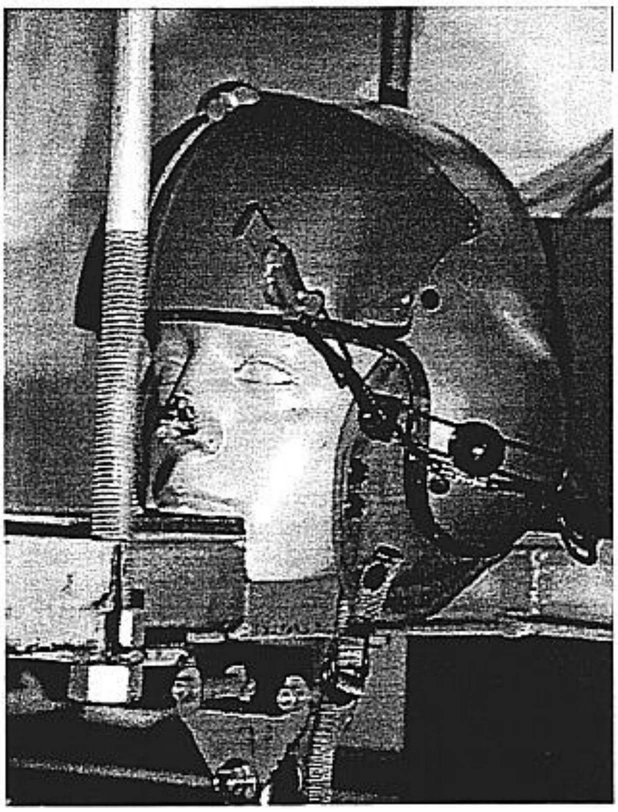

Figure 15. Chin strap static pull test setup.

6.2.2 Dynamic

The dynamic retention tests are conducted on a pendulum test device which has a Hybrid II head attached to a Hybrid III manikin neck at the end of the pendulum. Triangular shaped impact pulses from 10 to 15 G up to 25 to 30 G are applied to the pendulum beam in a rearward direction to the headform (a forward impact). The dynamic response of the helmeted head is recorded on video at 1000 images per second. Digitization of this data reveal relative angular displacements between the helmet and head. The test setup is shown in Figure 16. Graphical results of a prior study are provided in Figure 17. No absolute pass and fail criteria currently exist for dynamic retention performance. New systems and modifications are compared to the standard SPH-4B and HGU-56/P aircrew helmets.

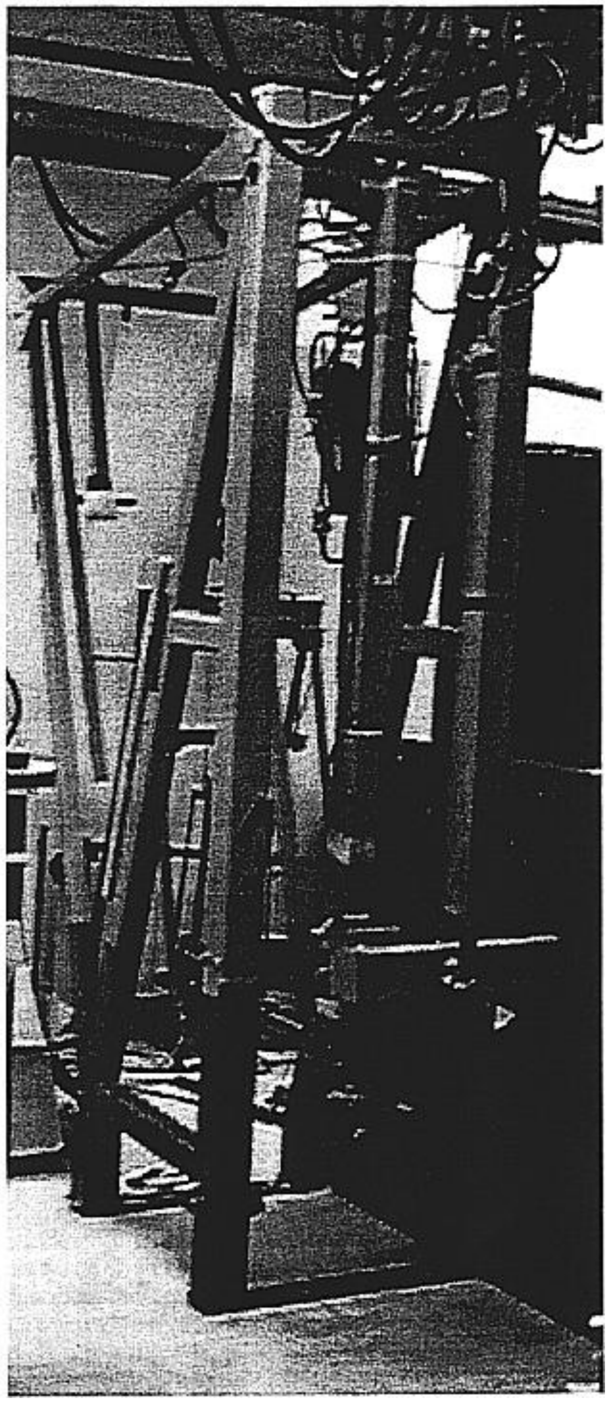

Figure 16. Dynamic retention pendulum tower.

6.3 Shell tear penetration

As a measure of shell integrity, a helmet shell tear penetration test is required on the HGU-56/P [11]. This requirement was not placed on any other helmet configuration, but the performance levels were established by testing standard SPH-4 (fiberglass) helmet shells.

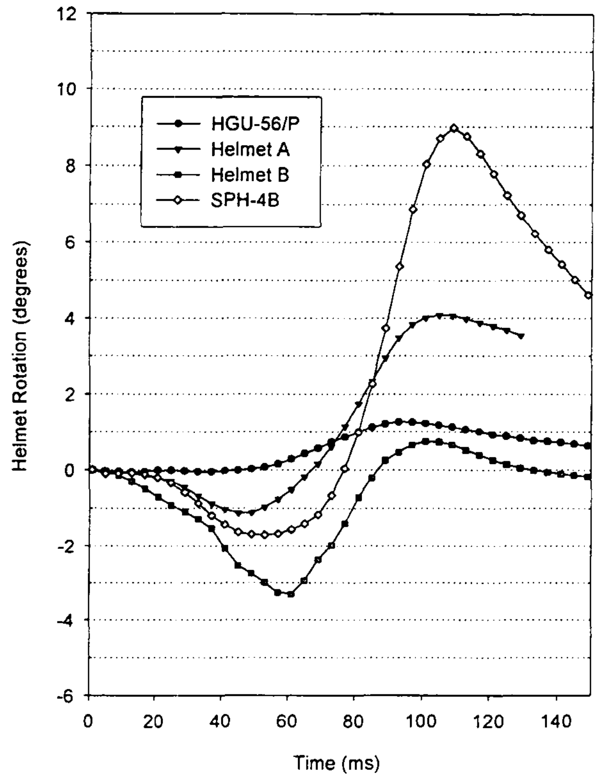

Figure 17. Dynamic retention test results.

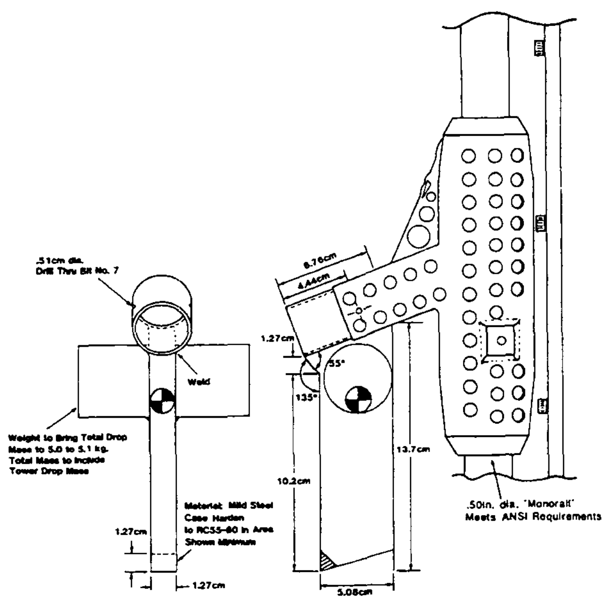

Figure 18. Helmet tear test penetrator.

The requirement is to drop a tear penetrator (shown in Figure 18) weighing 5 kg from a drop height of 1.52 meters. If the penetrator creates a tear length (measured along the shell surface) greater than 5 cm, the shell fails. The SPH-4 fiberglass helmet shells performed at this level. The SPH-4B Kevlar® shell and the IHADSS composite shell both fail to meet this requirement. This setup essentially tests the shell material in shear, in which graphite and Kevlar® perform poorly. The SPECTRA® rarely allows tearing to initiate, but allows the shell to buckle unless it is rigidly supported on its underside.

6.4 Sound attenuation

The ability of aviator helmets to reduce ambient noise levels remains a primary requirement. The performance requirements do not represent desired limits based on aircraft noise environments and human tolerance to exposure levels, but a reflection of state of the art performance. Table 9 provides the performance requirements of the HGU-56/P helmet when tested in accordance with ANSI S12.6-1984 [14]. To supplement the basic helmet performance, earplugs are required to be worn under the aviator helmets.

Table 9. Sound attenuation requirements.

Frequency (hz)	**HGU-56/P (dB)**
125	17
250	14
500	20
1000	21
2000	26
3150	38
4000	37
6300	44
8000	42

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